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1999 -01- 07

8171

PCT

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification [6] : H02K 3/487

A1

(11) International Publication Number: WO 98/34325

(43) International Publication Date: 6 August 1998 (06.08.98)

(21) International Application Number: PCT/SE98/00175

(22) International Filing Date: 2 February 1998 (02.02.98)

(30) Priority Data:
9700369-3 3 February 1997 (03.02.97) SE
9704433-3 28 November 1997 (28.11.97) SE

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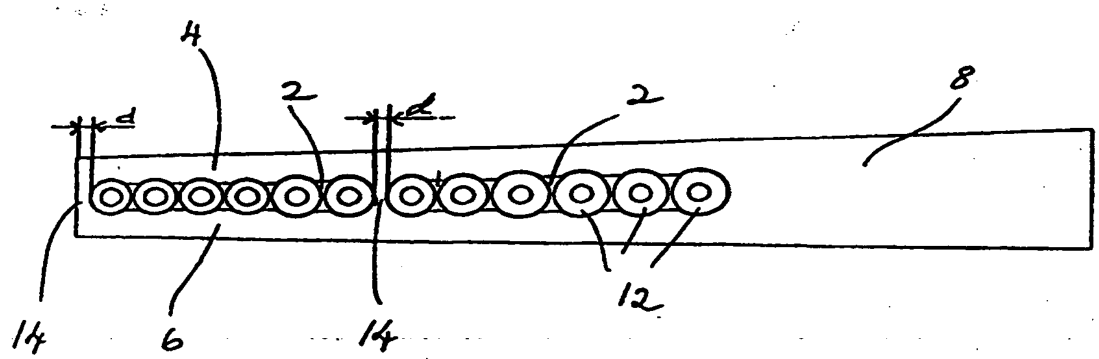
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, ES, FI, FI (Utility model), GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: A DEVICE IN THE STATOR OF A ROTATING ELECTRIC MACHINE



(57) Abstract

In a device for increasing the mechanical rigidity and natural frequency of the stator in a rotating electric machine, which stator is provided with stator teeth between the slots (2) holding the winding (12), stator teeth (4, 6), the free ends of which are situated at the air gap between stator and rotor, have at least one yoke (14) formed in one piece with adjacent stator teeth, arranged across each stator slot in order to mechanically secure the stator teeth in tangential direction.

*(Referred to in PCT Gazette No. 52/1998, Section II)

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A DEVICE IN THE STATOR OF A ROTATING ELECTRIC MACHINE

The present invention relates to a device for increasing the mechanical rigidity and natural frequency of the stator in a rotating electric machine, which stator is provided with stator teeth between the slots holding the winding, the free ends of the teeth being situated at the air gap between stator and rotor. The invention also relates to such a rotating electric machine.

High-voltage electric alternating current machines, such as generators in a power station for generating electric power, dual-fed machines, outer pole machines, synchronous machines and asynchronous static current converter cascades, have hitherto been designed for voltages in the range 15-30 kV, and 30 kV has normally been considered to be an upper limit. This generally means that a generator must be connected to the power network via a transformer which steps up the voltage to the level of the power network, i.e. in the range of approximately 130-400 kV.

In US 5,036,165, a conductor is described in which the insulation is provided with an inner and an outer layer of semiconducting pyrolized glassfiber. It is also known to provide conductors in a dynamo-electric machine with such an insulation, as described in US 5,066,881 for instance, where a semiconducting pyrolized glassfiber layer is in contact with the two parallel rods forming the conductor, and the insulation in the stator slots is surrounded by an outer layer of semiconducting pyrolized glassfiber. The pyrolized glassfiber material is described as suitable since it

retains its resistivity even after the impregnation treatment.

A solution to this problem is described in Swedish patent application 9602083-9 describing an arrangement in which separate spacers, such as slot wedges, are inserted in the space between the free ends of adjacent stator teeth. One drawback with this solution is that the slot wedges easily become loose as a result of vibrations in the stator and of different thermal expansion in the stator teeth and the slot wedges.

A special system of slot wedges intended to be inserted in stator slots is also disclosed in US 4,443,725. The purpose of this system of wedges is, however, not to increase the rigity of the stator teeth, but to retain the electrical conductors in place in the stator slots.

The object of the present invention is to provide a new solution to the problem of vibrations in the stator teeth in the type of alternating current machines under discussion, that is not encumbered with the drawbacks of the previous solution.

This object is achieved with a device of the type described in the introduction, having the characterizing features defined in claim 1, and with a machine as claimed in claim 10.

By providing at least one rigidity-increasing yoke across each stator slot in one piece with adjacent stator teeth, the risk of the yoke securing the stator teeth in tangential direction loosening is eliminated.

According to a preferred embodiment of the device according to the invention, the yoke is formed at the top

of the slot. This localisation of the yoke provides the best mechanical bracing of the stator teeth.

According to other advantageous embodiments of the device according to the invention, however, the yoke may be formed across the slot at a distance from the top of the slot, or alternatively a plurality of yokes may be formed across the slot at different distances from the top of the slot.

According to yet another advantageous embodiment of the invention, to enable the yoke to absorb the loads arising in tangential direction, the width in the direction of the slot shall not be less than a lower limit of typically 2-3 mm.
By closing the stator slot in this way, the electric properties of the machine may be affected negatively causing the yoke or yokes to give rise to increased slot leakage, with increased need for excitation at load as a result, i.e. an increased loss in the field winding. Increased slot leakage also influences the transient reactance of the machine.

Closing the slots also reduces slot harmonics in the air gap flux so that only a fraction remains, typically 5-15%, of the harmonics obtained with an open slot. Thus substantially all noise caused magnetically by slot harmonics disappears.

To reduce the above-mentioned increase in excitation losses with closed stator slots, according to advantageous embodiments of the device according to the invention the yoke is constructed so that its magnetic properties deviate from the magnetic properties of the stator teeth. The yoke may thus be constructed so that the relative magnetic permeability in the yoke material

is close to the value 1, by the yoke being perforated, for instance, or by the material in the yoke being worked, e.g. laser-worked, in order to lower its relative magnetic permeability, preferably to a value in the vicinity of 1.

The invention is in the first place intended for use with a rotating electric machine in which the stator windings are drawn through slots in the stator and the windings are wound from high-voltage cable of a type comprising a core with a plurality of strand parts, an inner semiconducting layer surrounding the core, an insulating layer surrounding the inner semiconducting layer, and an outer semiconducting layer surrounding the insulating layer. By using high-voltage insulated electric conductors, in the following termed high-voltage cables, with solid insulation similar to that used in cables for transmitting electric power (e.g. XLPE cables) the voltage of the machine can be increased to such levels that it can be connected directly to the power network without an intermediate transformer. The transformer can therefore be eliminated. In this type of machine the slots in which the cables are placed in the stator are generally deeper than with conventional technology, since thicker insulation is required due to higher voltage and more turns in the winding. This increases the problems of mechanical natural vibrations in the stator teeth between the stator slots. In a stator with deep slots damaging vibrations easily occur, generated by electro-magnetic forces and as a result of resonance phenomena, typically with a frequency of twice the network frequency. The advantages of the device according to the invention are therefore particularly pronounced for this kind of machines.

With the machine according to the invention the windings are preferably composed of cables of a type having solid, extruded insulation, such as those used nowadays for power distribution, e.g. XLPE-cables or cables with EPR-insulation. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The cable may preferably have a diameter within the interval 20-200 mm and a conducting area within the interval 80-3000mm^2.

In the machines according to the present invention, windings are constructed to retain their properties even when bent and when subjected to thermal stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in

the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butyl graft polyethylene, ethylene-butyl-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently great to enclose the electrical field in the cable, but sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface and the winding, with these layers, will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

The invention will now be explained in more detail with reference to the accompanying drawings in which Figure 1 shows a slot division in the stator with an open slot, Figure 2 a slot division designed according to the present invention, Figure 3 shows an alternative embodiment according to the invention and Figure 4 shows a cross section through the high-voltage cable used according to the invention.

Figure 1 shows a slot division of the sheet iron core in the stator, comprising a slot 2 and a part of the stator teeth 4, 6 on each side of the slot 2. The slot 2 is arranged to receive winding cables 12 running axially through the stator and the slots 2 are normally deeper in this type of alternative current machine than in conventional machines. This incurs the drawbacks of the stator having low natural frequencies and of oscillations easily occurring in the stator 4, 6, as mentioned above.

As can be seen in Figure 1, the slots 2 in this type of machine, contrary to conventional generators, resemble a bicycle chain with protrusions 10 between each cable 12 in the teeth 4, 6 located between the slots 2, so that the cable is secured radially. This type of slot is thus often known as "semi-closed", to differentiate it from conventional, open, rectangular slots with perfectly straight sides all the way out to the air gap.

The slot 2 is open to the air gap at the slot top, to the left in Figure 1. The opposite end of the slot is termed the slot bottom.

To manage the problems of natural vibrations in the stator discussed above, and to increase the tangential rigidity, yokes 14 are provided across the slots according to the invention, see Figure 2. In the embodiment shown in this figure a yoke is arranged at the slot top and another yoke is arranged at approximately the middle of the slot 2. The most efficient localisation of the yoke from the mechanical aspect is at the top of the slot. However, it may be a good idea to provide several yokes in the case of deep slots, and in certain cases it may be desirable not to have any yoke at the top of the slot, but only at points further down in the slot. The yoke (or yokes) 14 is made in one piece with the adjacent stator teeth 4, 6. The tangential stability achieved by the yokes 14 increases the natural frequency and provides considerably increased rigidity in each individual tooth, as well as increased flexural rigidity in the entire stator body. Another important advantage is that the tangential, electromagnetic forces at the air gap, deriving from the rotor poles, are distributed uniformly between the teeth.

To ensure that the yoke or yokes 14 will give sufficient mechanical bracing, their width d in the direction of the slot 2 should not normally fall below a limit of typically 2-3 mm.

As discussed above, the yokes cause increased slot leakage. The increased leakage flow limits the short-circuit currents in the case of any short-circuiting, and eliminates, or at least reduces, slot harmonics in the air gap flux. However, the increased slot leakage causes increased excitation losses. For this reason the yoke or yokes 14 should preferably be constructed so that their magnetic properties deviate from the mag-

netic properties of the stator teeth 4, 6. The yoke is preferably constructed so that the relative magnetic permeability in the yoke material is in the vicinity of the value 1. This can be achieved by perforation of the yokes, as shown in Figure 3 at 16. However, it must be ensured that the perforations do not jeopardize the stabilizing influence of the yoke or yokes. Alternatively, the magnetic permeability in the yoke material can be reduced by suitable treatment of the material, e.g. laser treatment.

Figure 4 shows a cross section through a high-voltage cable 29 used in the rotating electric machine according to the present invention. The high-voltage cable 29 is composed of a number of strand parts 31 having circular cross section and made of copper, for instance. These strand parts 31 are arranged in the middle of the high-voltage cable 29 and around the strand parts 31 is a first semiconducting layer 32. Around the first semiconducting layer 32 is an insulating layer 33, e.g. XLPE-insulation, and around the insulating layer 33 is a second semiconducting layer 34.

CLAIMS

1. A device for increasing the mechanical rigidity and natural frequency of the stator in a rotating electric machine, which stator is provided with stator teeth between the slots holding the winding, the free ends of the teeth being situated at the air gap between stator and rotor, **characterized** in that at least one yoke designed to increase rigidity and formed in one piece with adjacent stator teeth, is arranged across each stator slot in order to mechanically secure the stator teeth in tangential direction.

2. A device as claimed in claim 1, **characterized** in that the yoke is formed at the top of the slot.

3. A device as claimed in claim 1, **characterized** in that the yoke is formed across the slot at a distance from the top of the slot.

4. A device as claimed in claim 1, **characterized** in that the width of the yoke in the direction of the slot is not less than a lower limit of typically 2-3 mm.

5. A device as claimed in claim 1, **characterized** in that a plurality of yokes are formed across the slot at different distances from the top of the slot.

6. A device as claimed in any of claims 1-5, **characterized** in that the yoke is constructed so that its magnetic properties deviate from the magnetic properties of the stator teeth.

7. A device as claimed in claim 6, **characterized** in that the yoke is constructed so that the relative

magnetic permeability in the yoke material is close to the value 1.

8. A device as claimed in claim 6 or claim 7, **characterized** in that the yoke is perforated.

9. A device as claimed in any of claims 6-8, **characterized** in that the material in the yoke is worked in order to lower its magnetic permeability.

10. A rotating electric machine having windings drawn in slots in the stator, **characterized** in that the windings are wound of high-voltage cable and in that the machine is provided with a device as claimed in any of claims 1-9.

11. A machine as claimed in claim 10, **characterized** in that the high-voltage cable is of a type comprising a core with a plurality of strand parts, an inner semi-conducting layer surrounding the core, an insulating layer surrounding the inner semiconducting layer, and an outer semi-conducting layer surrounding the insulating layer.

12. A machine as claimed in claim 11, **characterized** in that the high-voltage cable has a diameter within the interval 20-200 mm and a conducting area within the interval 80-3000 mm^2.

13. A machine as claimed in any of claims 10-12, **characterized** in that the winding is flexible and in that said layers adhere to each other.

14. A machine as claimed in any of claim 10-13, **characterized** in that said layers consist of materials with such elasticity and such a relation between the

coefficients of thermal expansion of the materials that the changes in volume in the layers caused by temperature fluctuations during operation are absorbed by the elasticity of the materials so that the layers retain their adhesion to each other at the temperature fluctuations occurring during operation.

15. A machine as claimed in claim 6 or claim 7, **characterized** in that the materials in said layers have high elasticity, preferably with an E-modulus less than 500 MPa, most preferably less than 200 MPa.

16. A machine as claimed in any of claims 10-15, **characterized** in that the coefficients of thermal expansion for the materials in said layers are of substantially the same magnitude.

17. A machine as claimed in any of claims 10-16, **characterized** in that the adhesion between the layers is of at least the same magnitude as the strength of the weakest of the materials.

18. A machine as claimed in any of claims 10-17, **characterized** in that each of the semiconducting layers essentially constitutes one equipotential surface.

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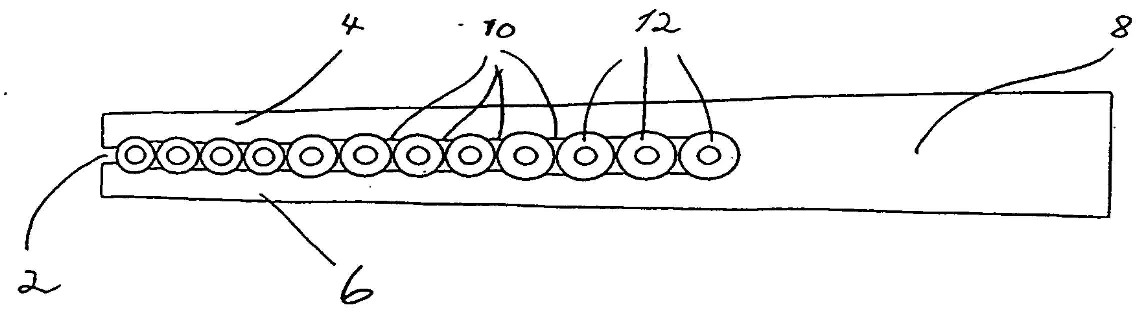

Fig. 1

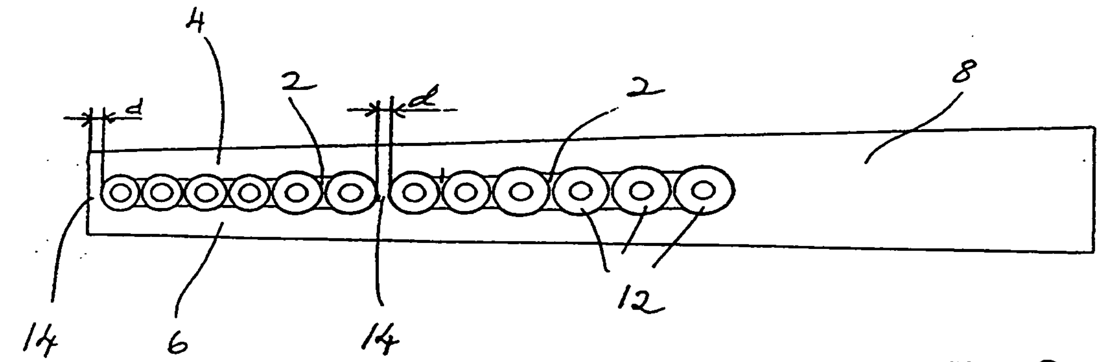

Fig. 2

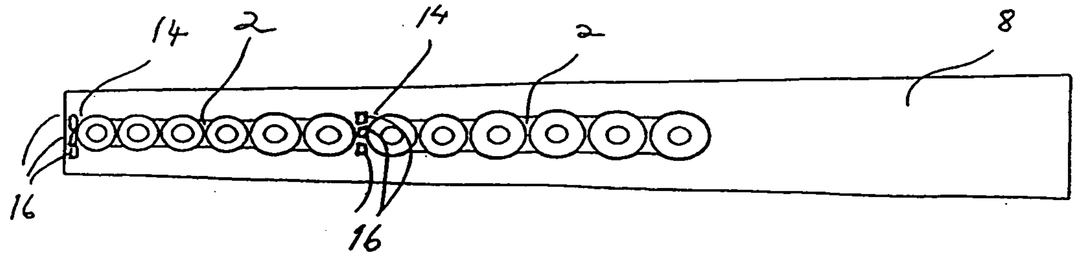

Fig. 3

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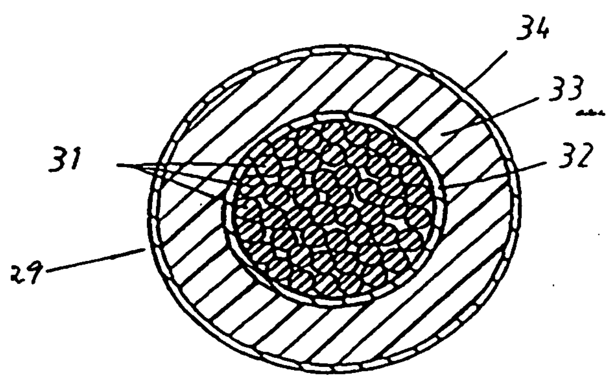

Fig. 4

INTERNATIONAL SEARCH REPORT

Information on patent family members

30/06/98

International application No.
PCT/SE 98/00175

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